GROUNDWATER FLOW, PERMEABILITY, AND PRESSURE

Lesson 4

LESSON 4 – GROUNDWATER FLOW, PERMEABILITY, and PRESSURE

Learning Outcomes -

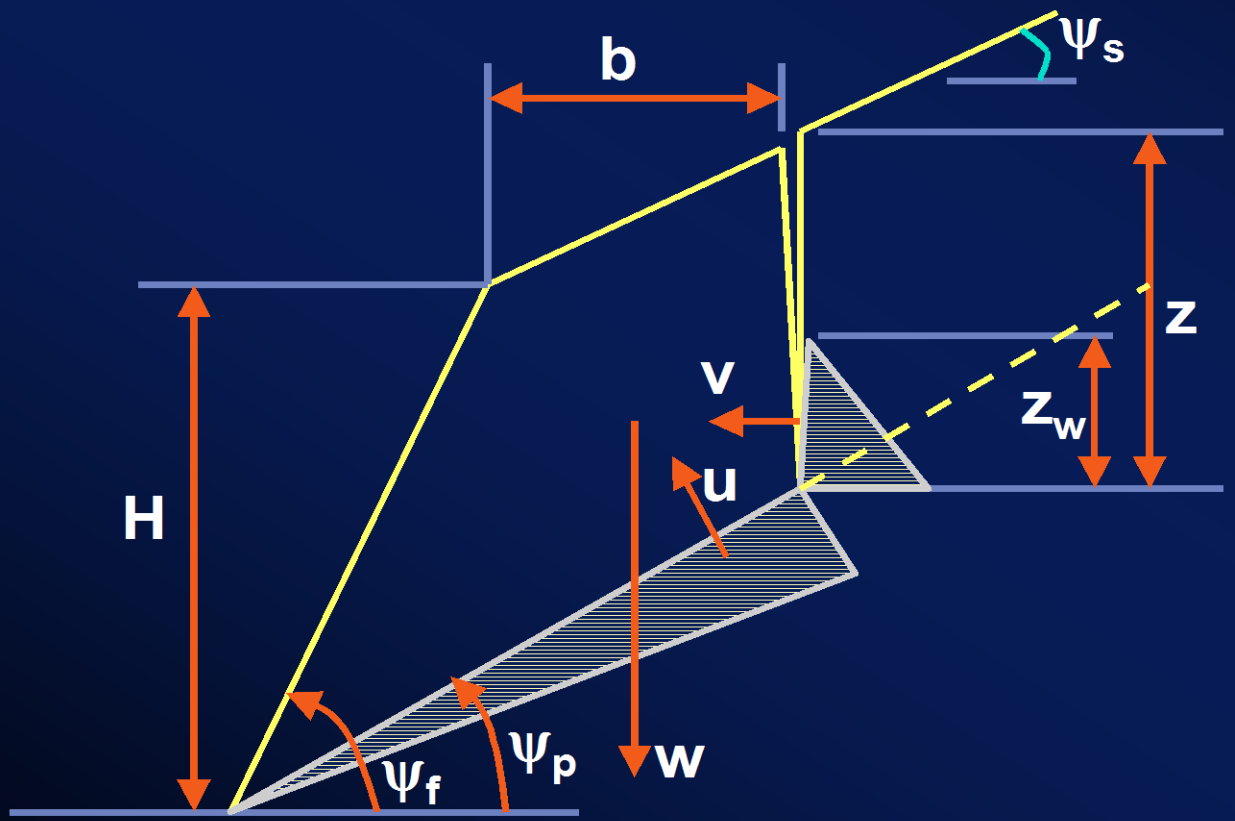
- Discuss effects of groundwater on rock slope stability;
- Define groundwater flow in rock masses – permeability and head (pressure) distribution;
- List factors influencing measurement of water pressure with piezometers.

Effect of Groundwater on Slope Stability

- *Reduces shear strength of sliding surface*
- *Induces thrust forces in tension cracks*
- *Changes in moisture content accelerate weathering*
- *Freezing induces wedging in open fissures*
- *Erosion of surface soils and weak infillings*

Factor of Safety Calculation

$$F = \frac{cA + (W\cos\psi_P - U - V\sin\psi_p)\tan\phi}{W\sin\psi_p + V\cos\psi_p} \qquad 5\text{-}2$$



Effect of Ground Water on Stability

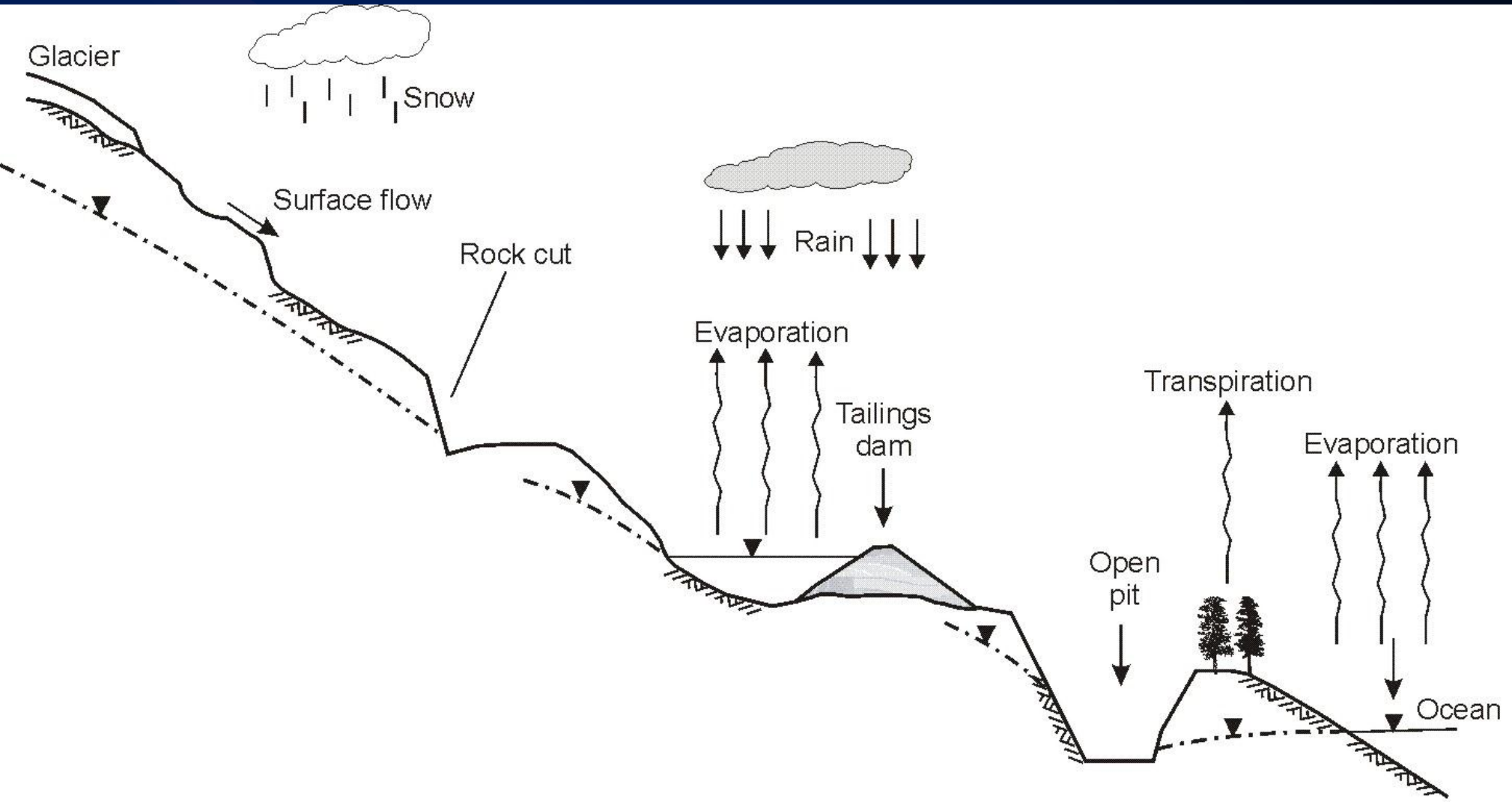
- **Water Force V Acts in Tension Crack**
  - Adds to Driving Force

$$V = \tfrac{1}{2}\,\gamma_w \cdot z_w^2 \qquad (5\text{-}5)$$

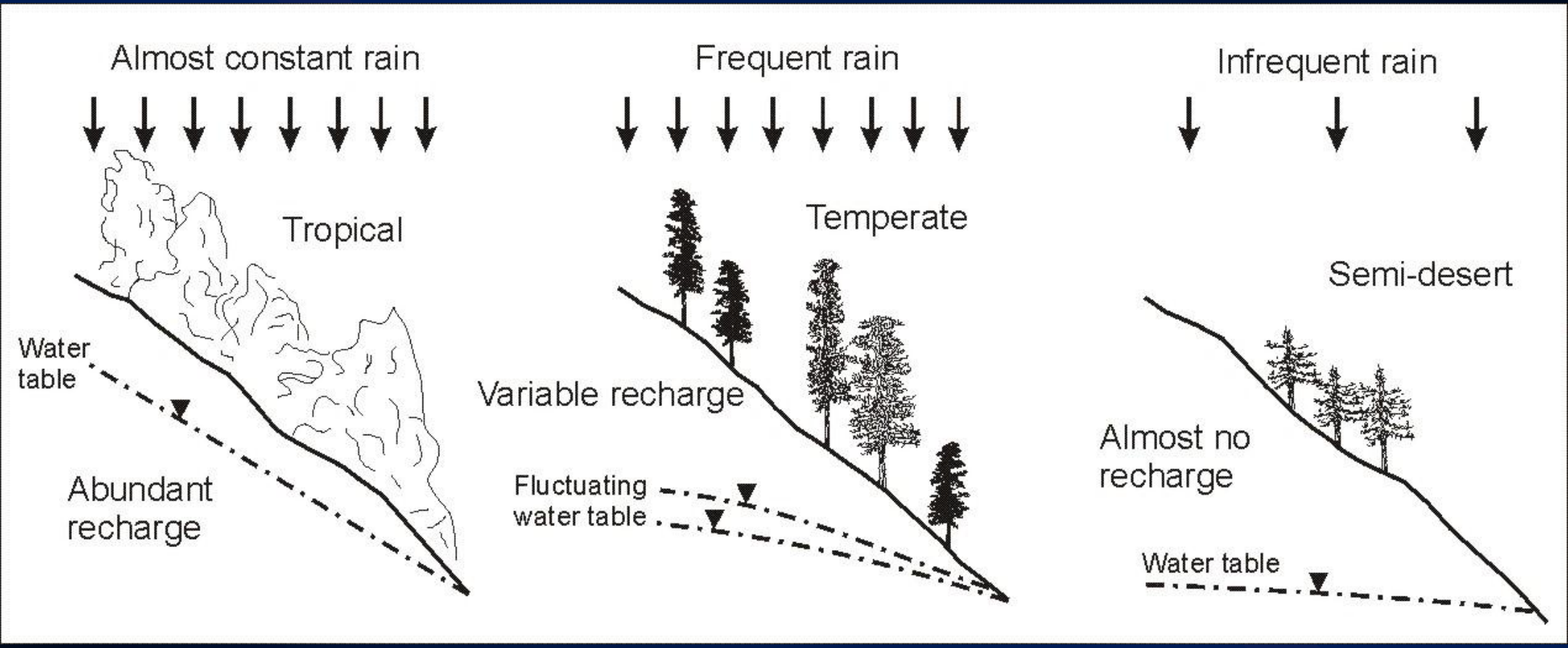
- **Water Force U Acts on Sliding Surface**
  - Decreases Normal Force

$$U = \tfrac{1}{2}\,\gamma_w \cdot z_w\,(H + b\tan\psi_s - z)\cdot \operatorname{cosec}\psi_p \qquad (5\text{-}4)$$

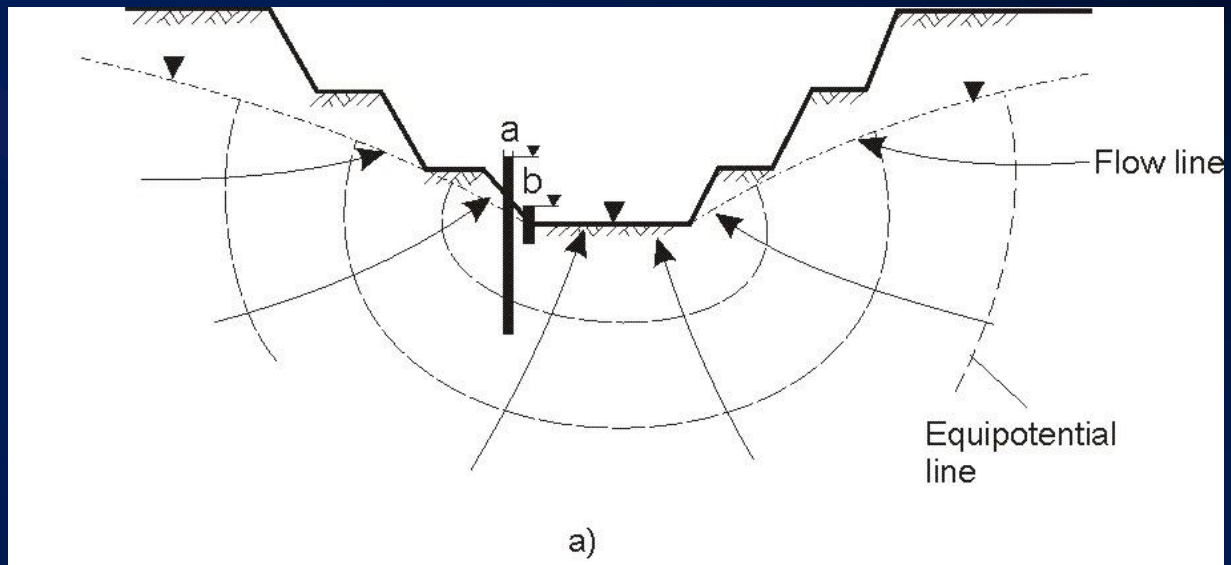
Hydrologic Cycle



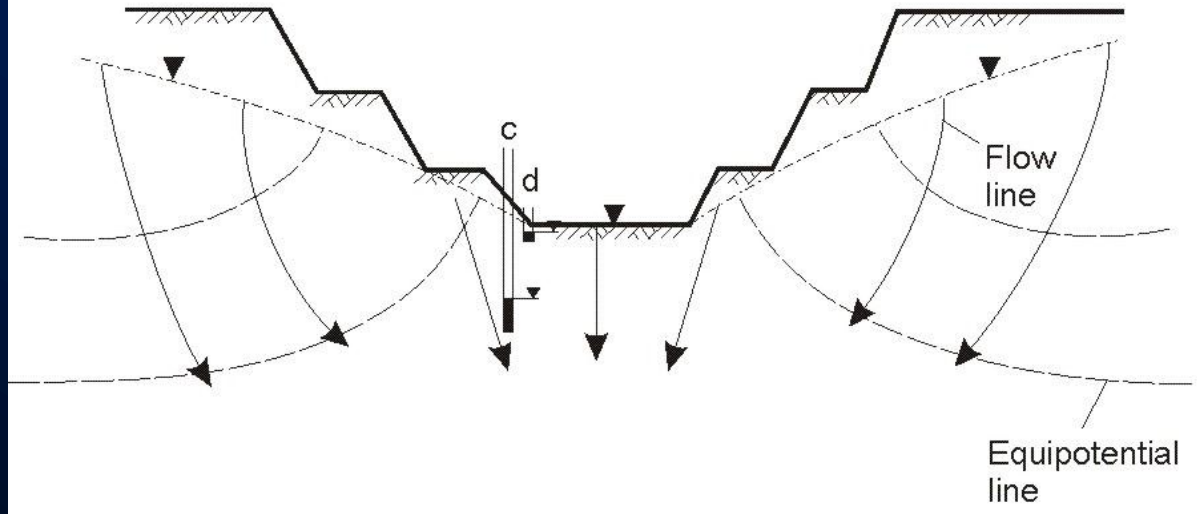
Hydrologic Cycle – Climate Effects



Groundwater Discharge and Recharge Zones

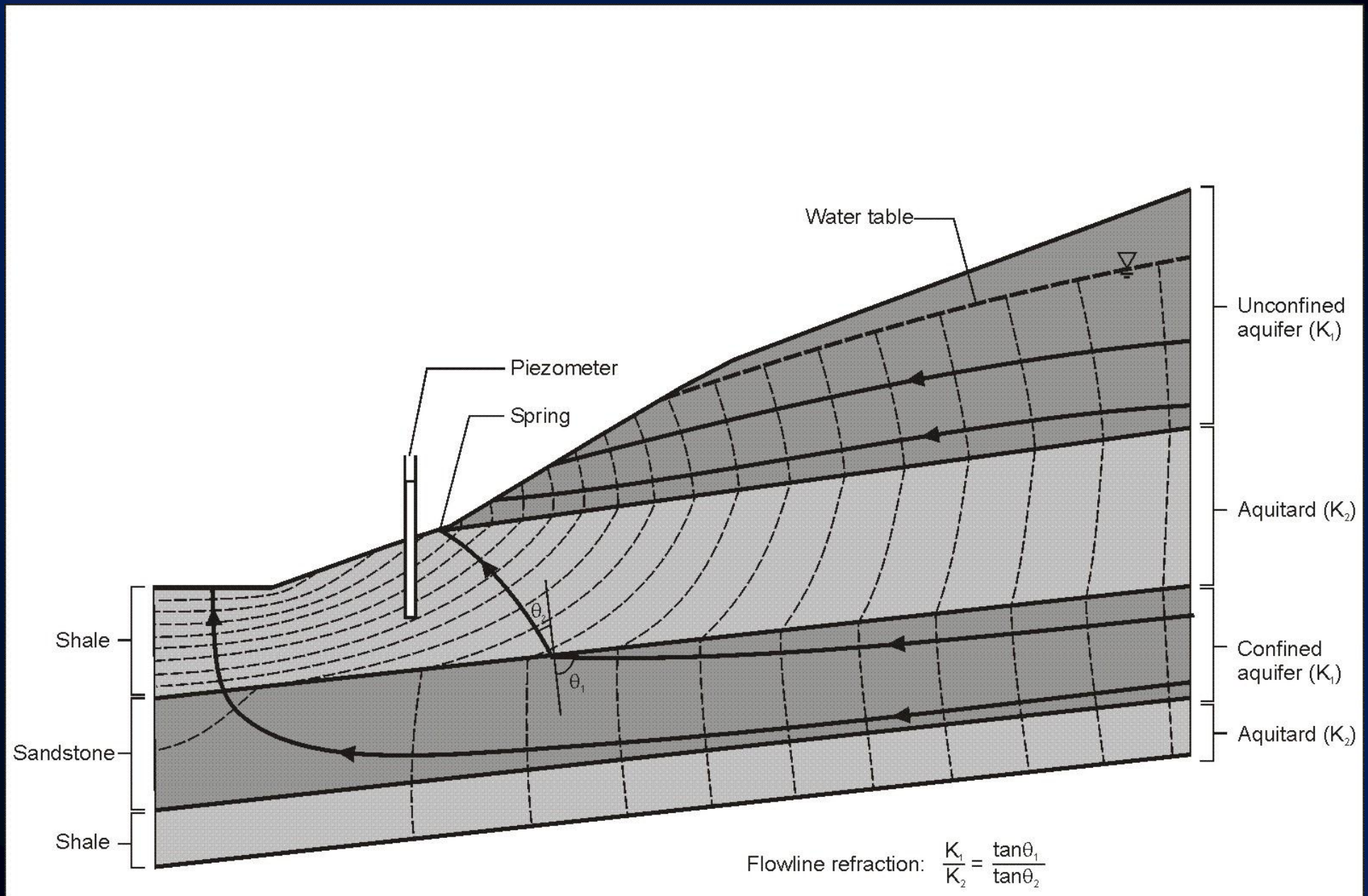


a)

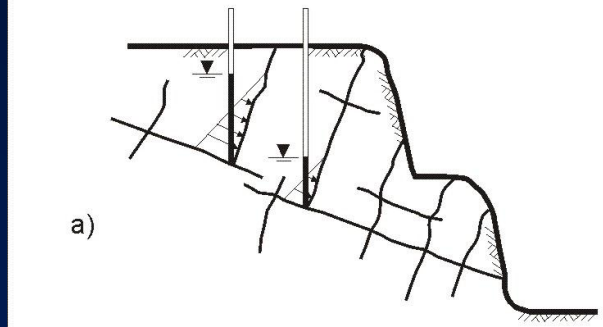


b)

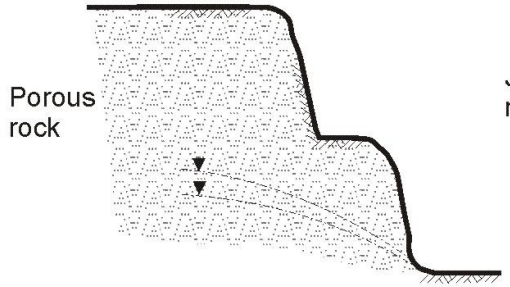
Effect of Permeability on Water Table

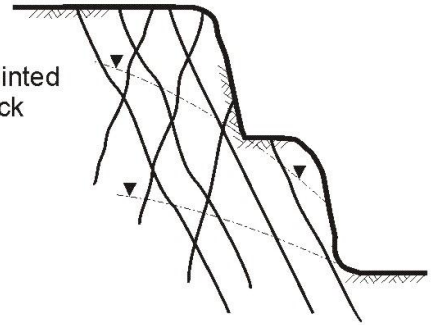


Flow Systems in Rock



a)





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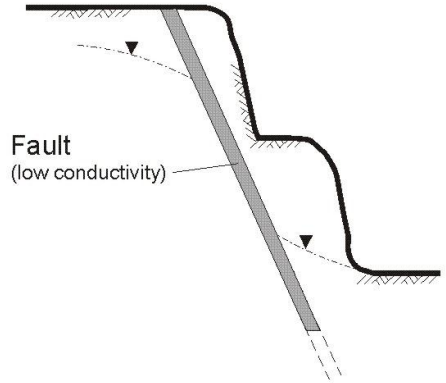
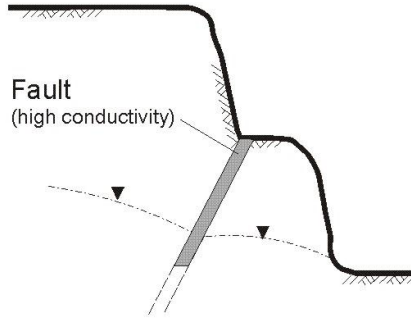
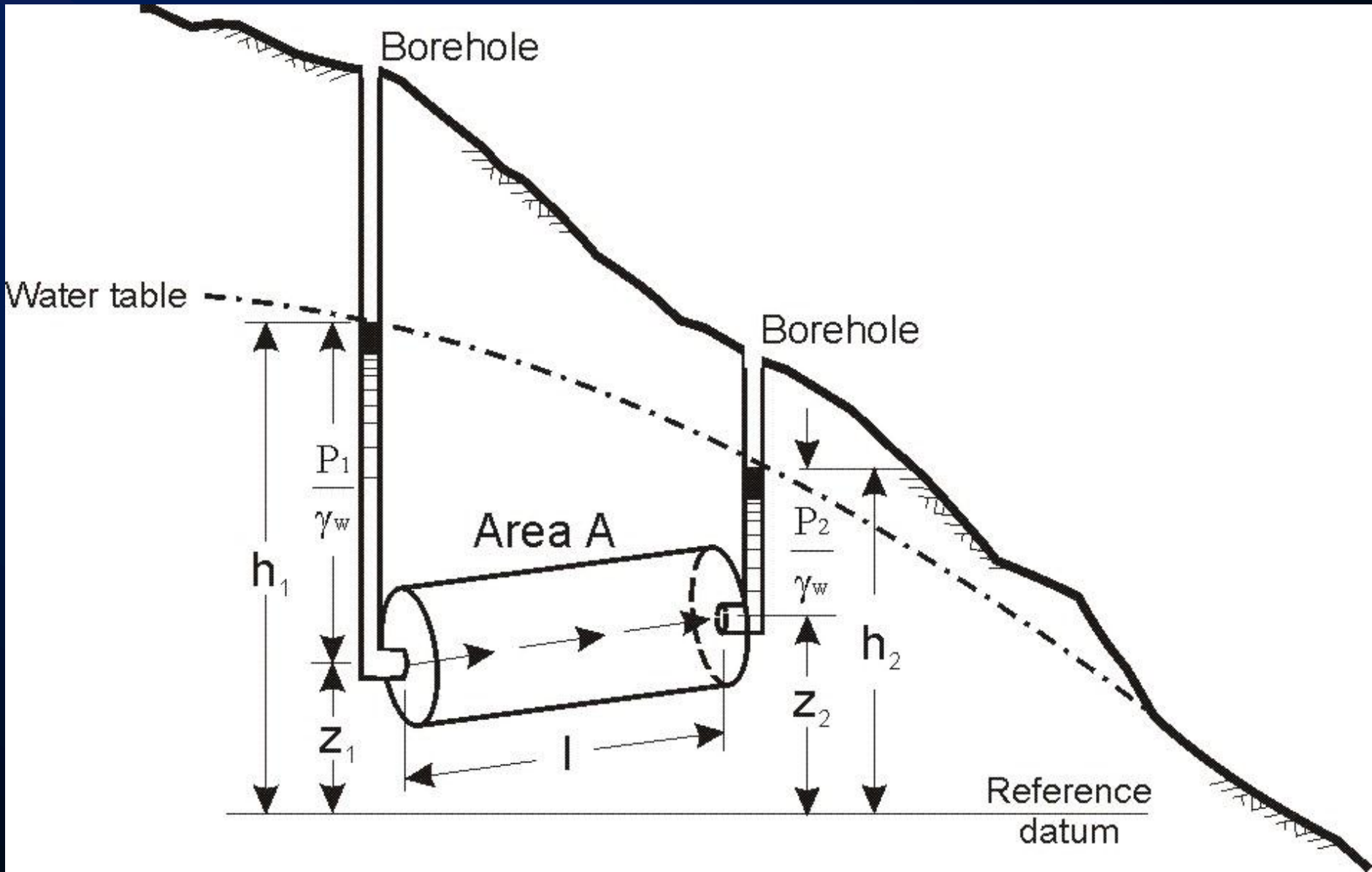




c)

Definition of Permeability - Darcy's Law



Darcy's Law - Calculation of Permeability, Head, and Flow

$$k = \frac{Q1}{A(h_1 - h_2)}$$

K = permeability (m/s)

Q = flow quantity per unit time (m^3/s)

L = path length (m)

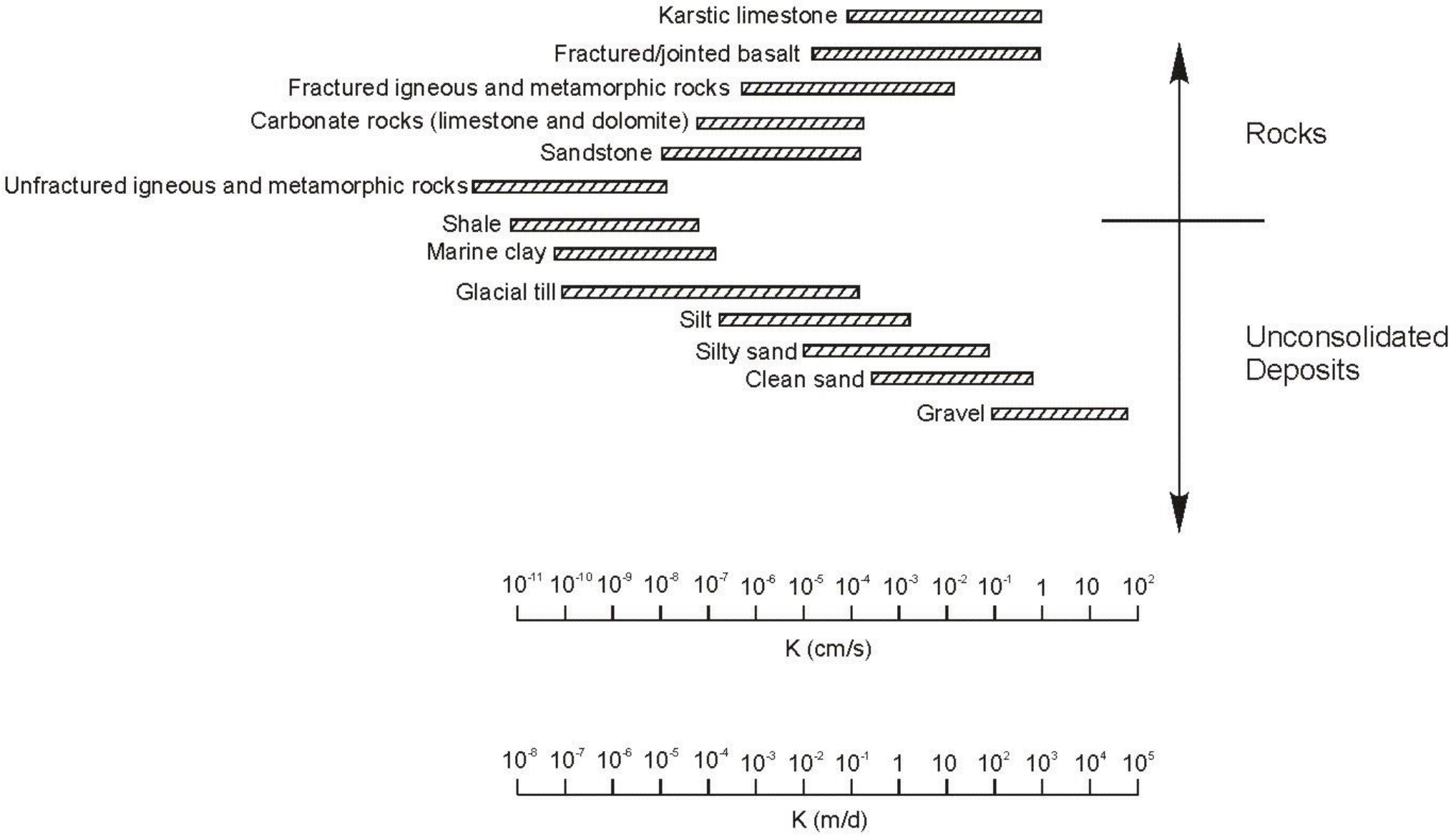
A = path cross-section area (m^2)

(h_1 - h_2) = head difference (m)

Range of Permeability for Rock and Soil

- Intact rock - shale, dolomite, granite:
  - 10^{-7} to 10^{-10} cm/s
- Fractured rock, clay-filled joints:
  - 10^{-3} to 10^{-6} cm/s
- Jointed rock, clean sand:
  - 10^{-1} to 10^{-2} cm/s
- Open jointed rock, karstic rock:
  - 10 cm/s
- Heavily jointed, blasted rock, clean gravel:
  - 10^{1} to 10^{2} cm/s

Range of Permeability for Rock and Soil



Permeability of Intact and Jointed Rock

- Permeability of intact rock (primary permeability) - very low
- Permeability of jointed rock mass (secondary permeability) - depends on joint spacing and aperture

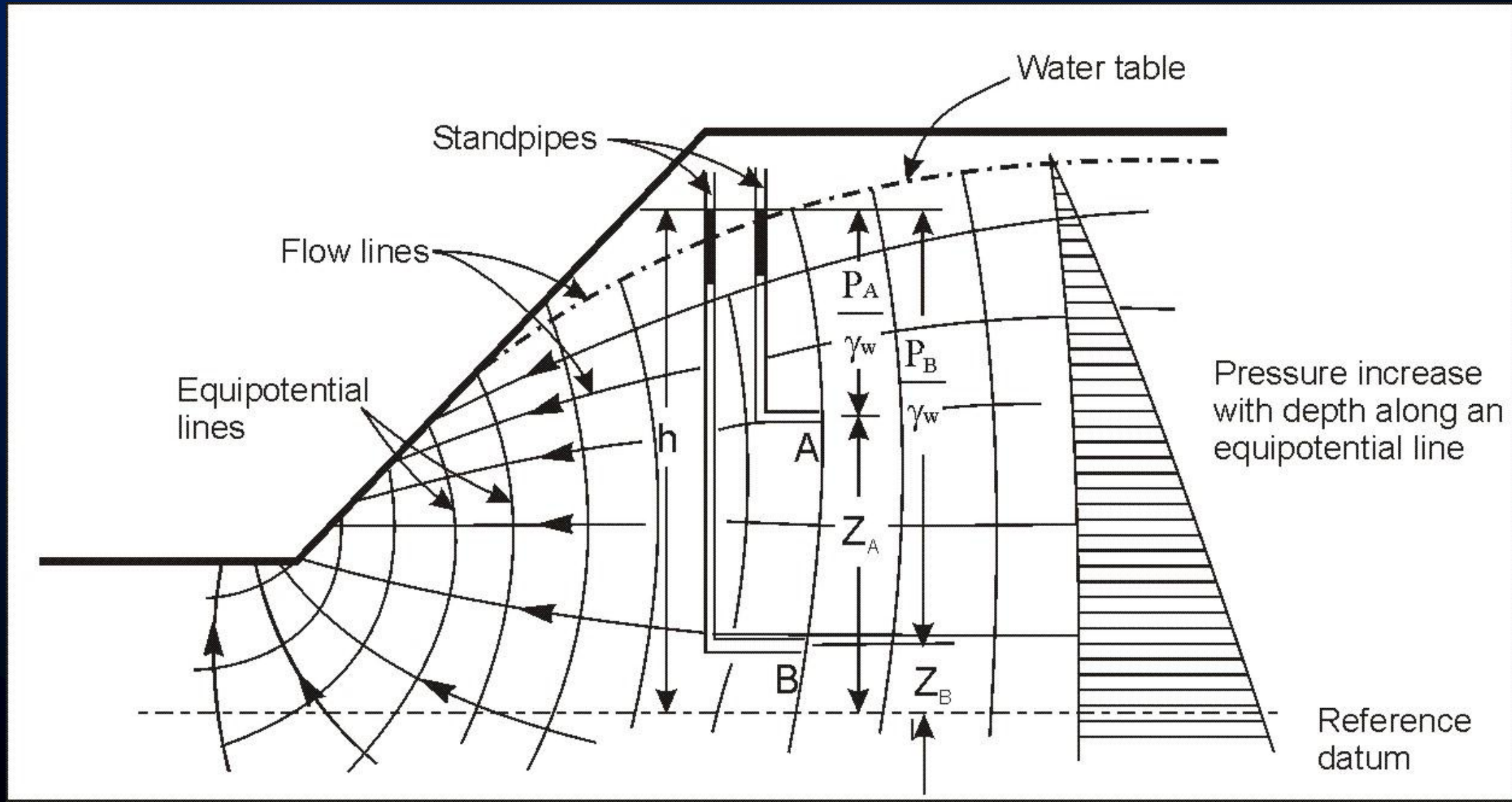
Permeability of Joint Systems

$$\text{Permeability, } k = f\left(\frac{(\text{aperture})^3}{(\text{spacing})}\right)$$

e.g. *Aperture = 1 mm, spacing = 1 m,*
$k = 8.1 \times 10^{-4}$ m/s

Aperture = 0.2 mm, spacing = 1 m,
$k = 6.5 \times 10^{-6}$ m/s

Flow Nets - Equipotential and Flow Lines

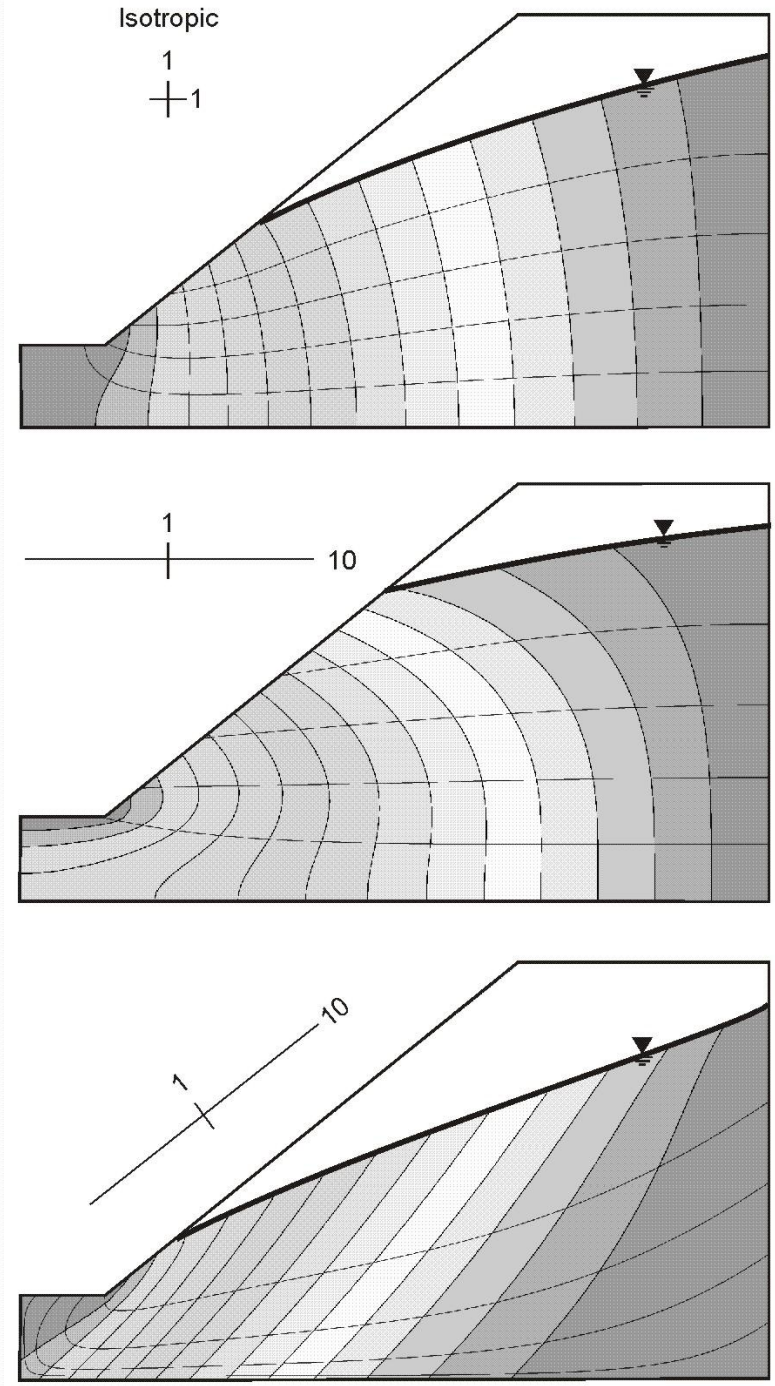


Effect of Anistropic Permeability on Pressure Distribution

Isotropic

Horizontally Bedded

Inclined Bedding



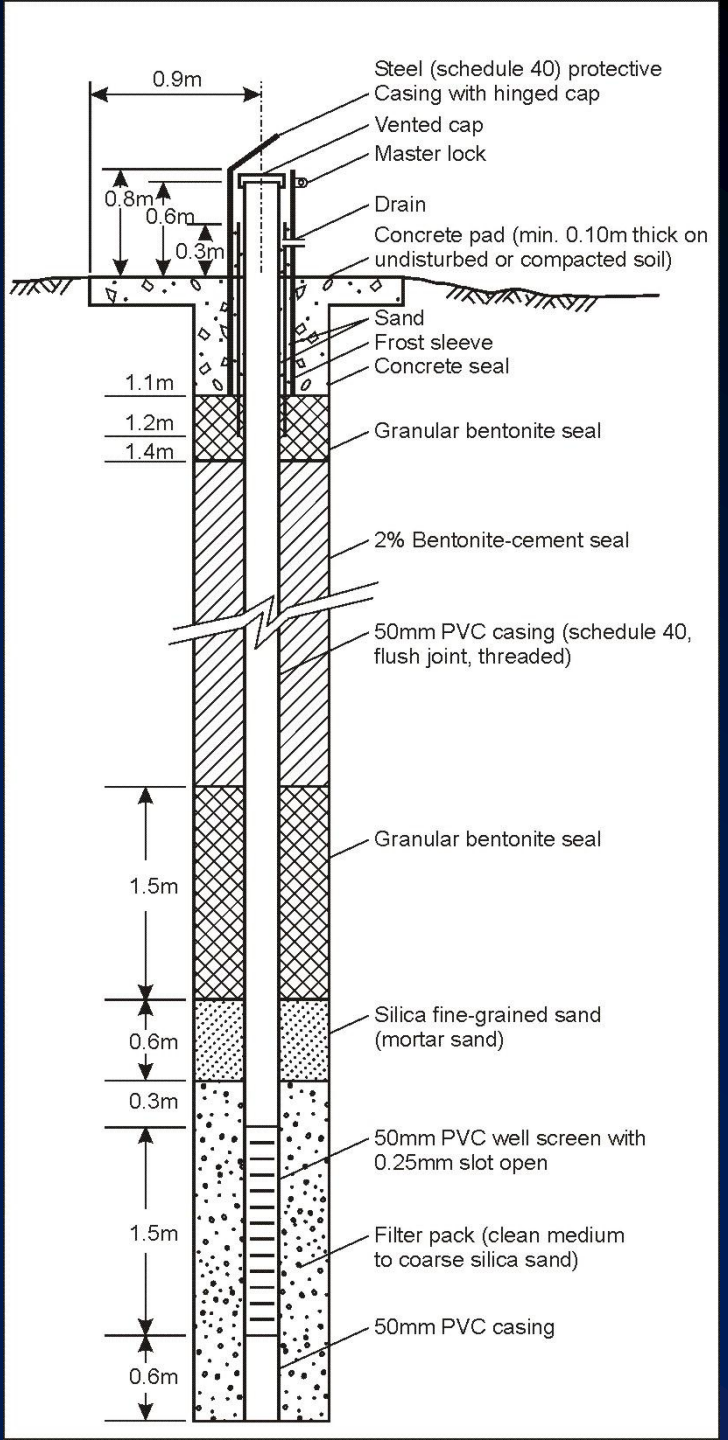
Measurement of Water Pressure

- *132041A – Geotechnical Instrumentation*
- *132031A – Subsurface Investigations*

Stand Pipe

CMT

Data packs



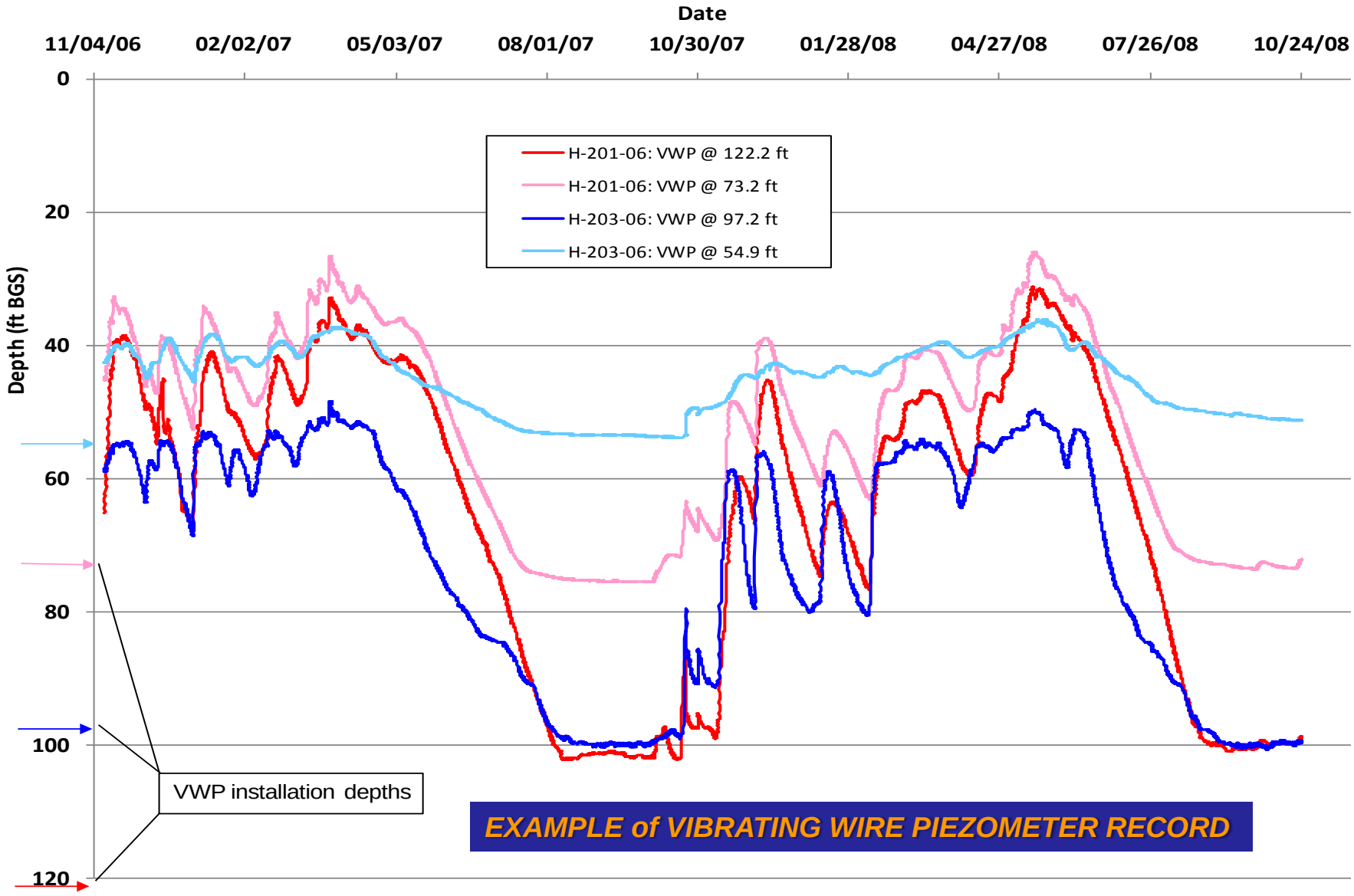


Figure 29

Piezometeric Data for Jenkins' Knob Vicinity

H-201-06 in Design Sector V, H-203-06 in Design Sector VI

Project No. 062-2002 Date: January 2009

I-90 Snoqualmie Pass East
Hyak to Keechelus Dam

Factors Influencing Installation of Piezometers in Rock

- *Orient hole to intersect discontinuities*
- *Position completion zone in jointed rock*
- *Effect of faults - high and low permeability zones*
- *Effect of rock types (e.g. sandstone and shale) with differing permeabilities*
- *Hydraulic time lag - standpipe, pneumatic piezometers*
- *Cost and reliability, access for readings*

Field Measurement of Permeability

Must disturb the groundwater regime by adding or removing water from the system and measuring the rate of recovery

Field Measurement of Permeability

- ***Variable head tests - e.g. falling head test in standpipe piezometer (Table 4-3, Page 4-13)***
- ***Constant head tests – e.g. packer test (Fig 4-9, Page 4-12)***
- ***Pump tests - pumped well and observation well(s)***

Groundwater Control – suit to geology

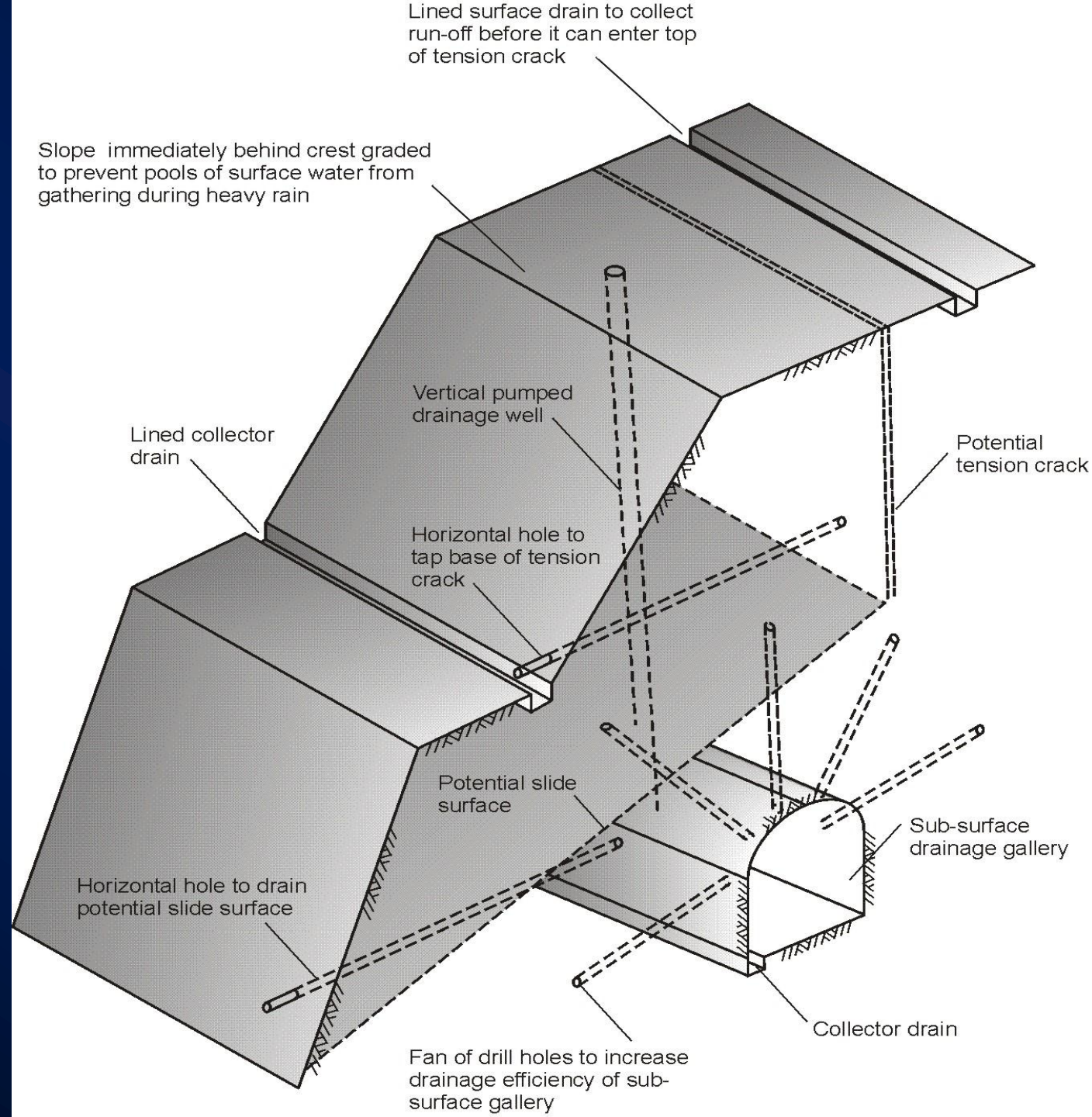
Ground Water Control

- **Passive Methods**
  - Horizontal drains
  - Adits/Galleries
- **Active Methods**
  - Pumped wells
  - Pumped shafts
- **Combinations**

Passive Horizontal Drains

Groundwater Control

Summary of options



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